Optimization and Development of Microstrip Antennas for 5G Technology Applications

Synopsis of the Research Proposal

Submitted for the Registration in the

Ph.D. Program (Part-Time) in Engineering

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Proposed Summary / Abstract

A Microstrip antenna is a single layer design consisting of four parts including patch, substrate, ground plane, and feeding part. It is designed on a printed circuit board using photolithographic technique. These antennas are used at microwave frequencies. The microstrip antennas are used in missiles, space craft, wireless communication system, remote sensing, and satellites. In telecommunication, micro strip antenna is an important component for communication process. The bandwidth of the antenna determines the speed and frequency in communication system. The low bandwidth is the main hindrance in the flawless speed of the communication devices. The speed bandwidth of the antennas can be increased by various means i.e., by increasing the thickness of substrate with low dielectric constant, by cutting notches and slots, by probe feeding and by changing the shapes of antennas.

Most of the existing Microstrip antennas are having narrow bandwidth. There is a direct relation between the bandwidth and the speed of the communication devices. If the bandwidth of the antenna increases, it also increases the speed of the antenna. A major challenge to meet the high speed of 5G technology applications is the narrow bandwidth of the existing antennas.

Considering the abovementioned challenges, this study attempts to design an antenna while optimizing it for the 5G technology applications. The study will use HFSS (high frequency simulation software) tool which is considered as the most appropriate tool to design an antenna. To design high speed antenna, this study will use all the four parts of antenna including patch, substrate, ground plane, and feeding part. For this, different parameters such as bandwidth, directivity, dimensions, and coverage area of the microstrip antennas will be used to increase the speed. The best results of these parameters will be used to design a high-speed antenna.

1. Introduction

An antenna makes a radio wireless device possible, a wireless communication device has two antennas namely, transmitting antenna at transmitter side and a receiving antenna on receiver side. The transmitter antenna takes signals from transmitter, converts them into electromagnetic wave and broadcasts them into free space. At the receiver side, the receiving antenna captures these electromagnetic waves and provide to receiver, which transforms into original signal. An antenna is a device to transmit and/or receive electromagnetic waves. Electromagnetic waves are often referred to as radio waves. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna is mainly used as a metallic device for radiating or receiving radio waves which is basically used for transmitting signals, transmitting antenna is used to transmit information and for receiving signal, receiving antenna is used at receiver end to receive signals.

An antenna is a transducer that converts radio frequency (RF) fields into alternating current or vice versa. There are both receiving and transmission antennas for sending or receiving radio transmissions. Antennas play an important role in the operation of all radio equipment. Hence an antenna plays a very important role in wireless communication systems. Antennas are used for both sending and receiving radio transmissions. Technologies such as radio and TV, mobile phones and Wi-Fi, connected cars, global positioning systems (GPS), space communications, radars etc. would not have been possible without antennas.

Antennas were designed to pick up electric fields, like the antenna are made with rods and plates while antennas made to pick up magnetic fields are made from loops of wire. Sometimes parts of electric circuits may have characteristics that unintentionally make them antennas

The fundamentals of antenna theory require that the antenna be "impedance matched" to the transmission line or the antenna will not radiate. The concept of VSWR is introduced as a measure of how well matched is an antenna’s bandwidth. The bandwidth of an antenna is the frequency range over which the antenna radiates.

1.1 Microstrip Antenna

One of the latest technologies in antennas and electromagnetic applications is development of micro strip antenna (also known as a patch antenna). Microstrip geometries which radiate electromagnetic waves were originally contemplated in the 1950. The concept of microstrip antenna was first

proposed by Deschampsin the year 1953. Gutton and Baissinot presented a patent on the microstrip antenna in 1955. Earlier specialized microstrip lines and radiators were developed in laboratories. During that period printed circuit boards with controlled dielectric constants were not commercially available and practically antennas were not fabricated. After 1970s prototype antenna was developed by Robert E. Munsonand practically demonstrated by Munson and Howell Extensive research and development of microstrip antennas and their arrays have led to diversified application of microwave antennas.

1.2 Types of Antenna

Depending on antenna structure, aperture size and their frequency, an antenna can be classified [1.1] as:

- Based on “Wire Structure”
- Based on the “Size”
- Based on the “Frequency”

1.2.1 Based on Wire Structure:

Wire antenna is the simplest form of the antenna configuration. Its oldest structure is regarded as simpler and cheaper. It is the most flexible antenna for many applications. Wire antenna can be further classified as:

(i). Dipole or Linear Wire Antenna: Dipole or linear wire antennas are an antenna in the form of straight wire.

(ii). Loop Antenna: Loop antenna is an antenna, where the single wire is used to form a loop. The loop can take any form, but mostly circular and square loop is used for the ease of analysis and construction.

(iii). Helical Antenna: Helical antenna is an antenna where the wire is bend in a helical shape. It is also termed as helix antenna.

1.2.2 Based on Size:

The different antenna that comes under it is as follows:

(i.) Horn Antenna: – It is an antenna which is constructed from the waveguide. The waveguide is a hollow metallic tube. The shape of the horn antenna depends on the cross section of this waveguide through which the waves propagates. When one end of the waveguide is trapped to a large opening then it acts as an antenna. The shape of the antenna is either rectangular or circular in shape.

(ii) Parabolic Disc Antenna: –It is an antenna having a shape of parabola. It is mostly used for very long distance reception or space reception. It is also termed as reflector antenna.

(iii) Microstrip Antenna: - It is an antenna having radiating patch etched on the substrate. The other side of the substrate is a metallic ground plane.

(iv) Array Antenna–It is an antenna formed by many single antennas cascaded. They are used when a single antenna is unable to give the desired features. The desired features can be achieved by using multi-element in the antenna structure.

1.2.3 Based on the Frequency:

An antenna can also be classified in terms of frequency, aperture, polarization and radiation. The frequency is the most important one among these. Therefore, in term of frequency specific class, the antenna classification is as follow:

(i) Very High Frequency (VHF) & Ultra High Frequency (UHF) Antennas: Yagi-Uda antennas, log periodic antennas, Helical antennas, Panel antennas, Corner reflector antennas, parabolic antennas, Disc one antennas are some of the antennas that operates in very high frequency (VHF- 30 MHz to 300 MHz) & ultra-high frequency (UHF-300 MHz to 3 GHz) range.

(ii) Super High Frequency (SHF) & Extremely High Frequency (EHF) Antennas: These are basically microwave antenna that operates beyond 3 GHz frequency range. The different antenna covers under this category are as parabolic antenna, pyramidal horn antennas, disc one antennas, monopoles and dipoles antennas, Microstrip patch antennas, fractal antennas, etc.

1.3 Characteristics of Microstrip Antenna

The Microstrip antenna has proved as superb radiator for many applications because of its several advantages as compared to conventional microwave antennas. Some of the major advantages are:

i. They act as an efficient radiator.

ii. They are easy to implement on the device

iii. They exhibit resistant to shock and vibration.

iv. They can be made conformal to planar and non-planar surfaces.

v. Their ease of mass production leads to a low fabrication cost.

vi.. They occupy low volume.

vii. They allow for dual and triple frequency operations.

viii. They allow both linear polarization and circular polarization with simple feed.

ix. They can be made compact for use in personal mobile communication.

x. They are of low profile planer configuration

xi. They are light in weight

xii. They have low scattering cross section.

xiii. They are mechanically robust when mounted on rigid surfaces.

xiv. They are well compatible for embedded antennas in handheld wireless devices.

xvi. They are easier to integrate with other MICs on the same substrate.

However, there are some Disadvantages as compared to conventional ones. These are:

i. They have low gain.

ii. The efficiency is low.

iii. They have narrow bandwidth

iv. They have low power handling capacity.

v. They have low isolation between radiating elements and feed.

vi.. Excitation of surface waves.

vii. Large ohmic loss in the feed structure of arrays.

viii. Extraneous radiation from feed and junctions.

ix. Complex feed structure required for high performance arrays

Besides, both advantages and disadvantages of microstrip antenna, there are some applications where the size of microstrip antenna is outsized for any use. The size of a microstrip antenna is inversely

proportional to its frequency. At frequencies lower than microwave, microstrip patches don't make sense because of the sizes required. The narrow bandwidth is one of the main drawbacks of these types of antennas. A straight forward method of improving the bandwidth is the increasing substrate thickness. However, with the increase of substrate thickness, surface wave power increases and radiation power decreases, which leads towards poor radiation efficiency. Therefore, various other techniques are presented to provide wide-impedance bandwidths of microstrip antennas. In principle, some of the techniques are suitable feeding techniques, impedance matching networks and insertion of slot, slit and notches on the microstrip antennas. Feeding technique has a large number of adjustable parameters like length, width and shape but with some limitations. Other ways to overcome these limitations are decreasing dielectric constant of the substrate, increasing thickness of the substrate and width of the patch.

Another problem to be solved is the low gain of conventional microstrip antenna. Cavity backing and lens covering are the two ways to improve the gain. Cavity backing has been used to eliminate the bidirectional radiation and thereby providing higher gain compared with conventional microstrip antenna. The integrated lens microstrip antenna can be treated as composite antenna combined by microstrip radiator elements and dielectric lens, which is very useful for high frequencies applications. Antenna array is also an effective means for improving the gain of the microstrip antennas.

The introduction of 5G technology has exposed the need for antennas, having high bandwidth to match with the increased speed of 5G enabled devices. 5G technology stands for 5th Generation wireless broadband technology. It has changed the user experience of high value technology. The 5G technologies include advanced features making 5G mobile technology powerful and in high demand in near future. In 5G technology, advanced billing interface will provide supervision tool of subscribers for fast actions. In addition, with unparalleled consistency 5G technology offer transporter class gateway. This gives a better and fast solution to the users. Advantages of 5G technology include bidirectional and high-resolution large bandwidth, more efficient and effectiveness, gathering of all networks on one platform, and facilitation of subscriber supervision. Moreover, this technology will support more than 65,000 connections, and will be giving large broadcasting data. 5G devices are having 10 Gbps peak data rate against the 1 Gbps data rate of 4G devices. Its maximum spectral efficiency is 30 bps/Hz and its maximum frequency is around 90 GHz. With this speed advantages 5G always remains the main motive of communication giants to innovate ahead of their competitors.

With the introduction of the 5G technology, the existing antennas seem unable to cope-up with the new technology. To overcome this challenge of slow speed, this study aims to design a new microstrip antenna for 5G technology to increase the bandwidth of the antenna. The new design will result into a new antenna with best efficiency for the 5G applications.

2. Literature Review

- **Brief Review of the selected paper**

Literature reveals that a lot of researches have been done in the field of microstrip patch antenna design and applications [ref]. Ample studies have been made based on the choice of substrate selection[ref], bandwidth expansions[ref], developing feeding techniques, improvement in gain, antenna array designing, substrate dimensions, and compactness of the antennas [ref] that motivates number of aspects to design compact and efficient microstrip antenna for broad band applications.

1. Yacouba et al proposed x band antenna suitable for microwave communications. They designed microstrip feed for low profile broadband dielectric resonator antenna. The length and width of antenna were taken 26.5mm and 1.2mm respectively. They used RT/Duriod substrate with permittivity 2.2. The reported that such antenna offers fractional bandwidth of 50% around the center frequency 10.16 GHz.

2. Deng et al proposed a C band antenna for satellite communications. Their antenna was in rectangular shaped with dimension of 40mm X 41 mm. They used FR4 substrate with height of 0.5 mm. The observed band characteristics were from 3.2 to 4.25 GHz and 5.05 to 6.15 GHz for Ultra-wide band applications.

3. Srilaxmiet al presented a single layer compact antenna for X band application, in which the designed antenna has the total size of 30mm X 22mmwith a patch size of 14.5 X 14.75 on FR4 substrate. Thickness of substrate was 1.6mm and relativity permittivity was 4.6. This double side printed antenna had shown bandwidth from 6.4 GHz to13.6 GHz. This symmetric proposed antenna showed an average gain of 4.1dB and stable radiation pattern.

4. Zivkovic et al presented a Box shaped antenna structure, the structure of the antenna was symmetrical and uniform. The monopole antenna has a dimension of 120mmx120mmx30mm for narrow bending. The broad bending was achieved on smaller dimension of 20mmx20mmx5mm .The radiating element was made from copper with epoxy substrate.

5. kim et al The design and analysis of a broadband dual polarized patch antenna on FR4 substrate was presented in this study. Accurate electrical characterization of the FR4 substrate in the 5G mmWave frequency band was also presented. A proximity L-probe-fed structure and parasitic patches were designed to improve the 10 dB impedance bandwidth of a square patch antenna, and the measured fractional bandwidth of the proposed antenna was 23.1 % (23 _ 29 GHz).

6. Yang et al studied a frequency reconfigurable microstrip patch antenna and designed a frequency tunable antenna by adding a U slot of dimension 32mm X 31 mm on the patch of dimension 77mm X 57 mm. The substrate of dielectric constant of 2.4 and thickness of 1.524mm was used. They found the fabricated prototype antenna attains a tunable frequency ranging from 2.6 to 3.35 GHz which is suitable in multichannel systems to reduce crosstalk from adjacent channel.

7. Islam et al designed microstrip antenna for L band wireless communication system applications. The height of substrate was taken 12.5mmwith patch size is 79mm X 53 mm. They used coaxial probe feeding technique. They designed patch in such a way that it comprised of 3 slit on one side of same length but different width of 5mm, 10mm and 15 mm respectively. As a result of effect of multi slotted patch substrate, they achieved high gain~5 dB and bandwidth of 27.62% in L band frequency range.

8. Liu et al proposed multi-layered planner structures microstrip antenna of 62.5mm X 62.5mm dimension. The permittivity of the layer was taken as 2.2 and 2.6 respectively. They found that the bandwidth of L band increases up to 25.7%, with VSWR less than 2 and high gain.

9. Rahayu et al [2.8] presented a slotted antenna by using different type of slots such as ring slot, L slot and T slot. They showed simulation results with different combinations of the slots. The simulation result reveals that the best resonance occurred at 5 GHz with -40 db reflection coefficient that are useful in WPAN application.

10. He et al [2.9] proposed E shaped antenna for millimeter frequency range. E shaped patch was designed with 7mm X 8mm dimension. The height of substrate was taken0.8mm with permittivity of 3.7. They reported that the bandwidth of such antenna was from 31 GHz to 40 GHz with good impedance matching.

11. Murugan proposed the work is to design a compact MIMO antenna at 3.5 GHz suitable for 5G applications. MIMO antenna is suitable choice for increasing the signal to noise ratio of mobile communication systems. He found a four element shorting pin loaded patch antenna is designed at sub 6 GHz 5G band which covers the frequency range from 3.4 GHz to 3.5 GHz and reasonable gain of 4 dB is obtained. The gain and radiation efficiency of the proposed 4 element antenna is increased compared to two element and unit element antennas. The volume of the proposed antenna is 1084 mm 3, which is suitable for mobile handsets.

12. Lau et al proposed circularly polarized vertical antenna by simply adding two small stubs to the vertical patch. The frequency range obtained from simulation result was from 4GHz to 5.5 GHz. They observed that at operating frequency the value of VSWR lies below 2.

13. Tammam et al proposed a small size monopole antenna suitable for WLAN and WiMAX application. They selected semicircular patch etched on epoxy substrate of size 12mm X 18mm with partial ground plane. The bandwidth achieved by optimization of the slot's width and ground plane.

14. Huque et al designed microstrip array antenna with series feed. They used dielectric substrate of permittivity 2.2 and height 1.5. The designed antenna delivers reflection coefficients in the range of -4.21 dB to -25.45dB at around 10 GHz resonance frequency. The gain of the antenna was found 15dB.They found application of such antenna in x band communication like satellite communication, radar, mobile, medical applications and other wireless systems.

15. Deshmukh et al suggested E shaped microstrip patch antenna slot for ISM band applications. The length and width of antenna were taken 27.5mm and 37mm respectively. The height of substrate was taken 0.158mm with permittivity of 4.2mm. The design was achieved by simply adding two small slots to the E shaped patch and obtained operating frequency range from 2.35GHz to 2.45 GHz from simulation result.

16. Devang et al proposed a 2 X 2 small size micostrip antenna array for wireless applications. They used RT roger as substrate material with permittivity of 2.2 and thickness1.5mm. The simulation results shows that at operating frequency less than 10 GHz, the reflection coefficient, VSWR and gain were -40.4 dB,1.0 and 13.3 dB respectively with 99.23%radiation efficiency.

17. Azim et al proposed a tapered shaped slot antenna for ultra wide band application. The optimization has done by taking in to account for the circular, elliptical, square, rectangular and

tapered shape slot on top of the patch and tuning stub .They observed VSWR less than 2 with frequency range from 3 to 11.2 GHz.

18. Lee et al proposed slot antenna with50mm X 50mmdimensions over theFR4 (relative permittivity 4.4) substrate of thickness 0. 8mm.They nested a pair of C shaped stubs along with the feed lines in such a way that it captures all input power at its resonance frequency. Finally they obtained operating bandwidth from 2.4GHz to 11.6 GHz and VSWR value less than 2. They suggested that proposed antenna is good for various wireless applications such as Wimax, Wireless LAN etc.

19. Sadat et al proposed micro strip square antenna with a ring slot. RO substrate of dimensions 120 mmX 100 mm is used for fabrication. They found that this antenna provides VSWR less than 2 and reflection coefficient -8.5dB.

20. Lechet al proposed a unique ground flexible microstrip antenna for wireless application. They used substrate of dielectric constant of 3.44, height of 0.25 mm with dimensions 7 cm x 7 cm. They designed antenna by using two circular coplanar strips curved on this substrate. They reported that this antenna shows reflection coefficient of -13 dB, and bandwidth from 3 GHz to 15 GHz frequency range.

21. Ghassemi et al presented multilayer microstrip antenna. They used Roger Duriod substrate with permittivity 2.2. They achieved band width up to 4.0 GHz with single slot and up to 4.2 GHz with double slot. They also observed VSWR less than 2 with 8 dB gain.

22. Latif et al prepared printed monopole slot antenna of three different shapes namely straight shaped, L shaped and inverted T shaped by proper selection of antenna parameters such as stub length, feedline length, position over the slot, etc. They reported that the designed antenna exhibit wide impedance bandwidth on introducing L and inverted T slots. The measured impedance bandwidths of about 60%, 84%, and 80% for the straight, L- and inverted T-slot antennas.

23. Gao et al proposed a very simple broad band microstrip antenna by using only single patch. They used circular patch as the main radiator and a H-shaped slot cut in the ground plane below the feed line. A stepped-width microstrip line was used to feed the patch through proximity coupling. They reported that the prototype antenna achieves impedance bandwidth of 26%.

24. Elkorany et al proposed a double slot rectangular microstrip patch antenna. They designed antenna on epoxy substrate of dimension 100 mm X 100 mm X 4 mm. The rectangular patch size was

taken 30mm X 40 mm. The desired UWB frequency was obtained by optimizing the height of the substrate and varying position of slot. Such antenna depicts resonance from 4 to 10 GHz frequency range.

25. Anget al proposed a wideband E-shaped microstrip patch antenna for high-speed wireless communication systems. A substrate with dielectric constant of 2.2 and thickness of 3.2 mm was taken. They observed that the reflection coefficient was below −10 dB from 5.05 GHz to 5.88 GHz operating frequency.

26. Womg et al proposed a circular microstrip antenna for wideband application. The bandwidth of their designed antenna was 3.2 times that of a conventional circular microstrip antenna.

27. Ramli et al proposed a 3.5 GHz microstrip patch antenna using three different substrates materials with varying relative permittivity have been designed. the thickness of the substrates is slightly different from each other which is 1.6 mm for FR-4, 1.575 mm for RT-5880 and 1.58 mm for TLC-30 have been chosen to carry out this work. The results and the comparison between substrate materials FR-4, RT-5880 and TLC-30 has been extensively studied. The aim of the proposed antenna designs was to achieve good performance in terms of gain and bandwidth while maintaining a reflection coefficient below -10dB and VSWR ≤ 2.

28. Paul et al proposed a directional wideband microstrip line fed rectangular patch antenna has been proposed for the 28 GHz 5G applications. They observed a piece of 20 × 17 × 1.575 mm3 Rogers RT5880 material having dielectric constant of 2.2 and loss tangent of 0.0009 is used as a substrate of the proposed cutting edge patch antenna. At step-1 of cutting edge design, a parasitic element is introduced with the main radiating metallic patch to achieve higher gain and directivity.

29. Mohammed et al proposed an Improving the Gain Performance of Air Substrate Patch Antenna Array Using the Effect of Conductive Material Thickness Study for 5G Applications. A novel 4-element array of microstrip patch antenna with a high gain and good matching capability operated at 28 GHz resonance was proposed in this paper. The proposed design was succeeding in combining the benefits of high gain, compact size, and cost-effective antenna manufacturing. The operating frequency of the antenna was adjusted by varying the thickness of the resonator, ground and substrate.

30. Paul et al proposed an antenna provides excellent performance metrics for 5G communications. The -10 dB bandwidth is 4.846 GHz that supports huge data capacity. The values of S-parameter and VSWR are -35.03 dB and 1.036, respectively. The antenna also possesses good average radiation efficiency (≈ 70%) with acceptable gain over the entire large operating frequency band.

3. Present Study

A high-speed electronic device such as satellite, mobile phone and computer helps in fast processing of the digital works. This will improve the work efficiency both in the public and private sector and will yield higher output. Existing microstrip antennas face a major challenge of narrow bandwidth causing slow speed of the digital applications. Moreover, with the introduction of the 5G technology, the existing antennas seem unable to cope-up with the new technology. To overcome this challenge of slow speed, this study aims to design a new microstrip antenna for 5G technology to increase the bandwidth of the antenna. To design a new high bandwidth antenna this research will set optimum parameters of the antenna by using HFSS tool. The new design will result into a new antenna with best efficiency for the 5G applications.

4. Methodology

Ansys HFSS (high-frequency structure simulator), is a commercial finite element method solver for electromagnetic (EM) structures from Ansys that offers multiple state-of-the-art solver technologies. Each solver in Ansys HFSS is an automated solution processor for which the user dictates the geometry, properties of the material and the required range of solution frequencies. Ansys HFSS primarily to design and simulate high-speed, high-frequency electronics in radar systems, communication systems, satellites, ADAS, microchips, printed circuit boards, IoT products, and other digital devices and RF devices. The solver has also been used to simulate the electromagnetic behavior of objects such as automobiles and aircraft. ANSYS HFSS allows system and circuit designers to simulate EM issues such as losses due to attenuation, coupling, radiation and reflection.

The benefits of simulating a circuit's high frequency behavior with high accuracy on a computer reduces the final testing and verification effort of the system as well as mitigating the necessity of building costly multiple prototypes, saving both time and money in product development.

Ansys HFSS is a high-frequency structure simulator that can be used to design and simulate high-frequency electronic items. This includes: antennas, antenna arrays, RF or microwave components, high-speed interconnects, filters, connectors, IC packages, and printed circuit boards. Ansys HFSS software is used by engineers all over the world to develop high-frequency, high-speed electronics that can be found in communications networks, advanced driver assistance systems (ADAS), satellites, and internet-of-things (IoT) devices.

- Component-to-System EM Workflow
- Encrypted 3D Design Share
- Coupled EM System Solver
- Automatic Adaptive Meshing

The leading adaptive network technology provided by HFSS tool gives design sign-off accuracy. Its powerful network and solver technologies assist to design with assurance, and the results can be easily relied on. Other tools merely give answers without any feedback leading to uncertainty of the solutions. Combined with domain decomposition or distributed frequencies of Ansys HPC, HFSS can simulate the never thought speed and scale at a speed and scale of the devices. This optimizes the device's performance and explores it to its fullest capacity. The designs with HFSS deliver on the product promise. The patented technology of HFSS Mesh Fusion enables much more complex designs with the same precision, accuracy, and consistency of Ansys HFSS. It completes this by using targeted networking technologies within the identical design, applicable to the local geometry. HFSS Mesh Fusion continues to remain same with the "electromagnetically aware" adaptive meshing technology without conceding accuracy due to fully coupled electromagnetic matrix, solved with each adaptive mesh step and point in a frequency sweep.

5. Work Plan of the Research

- **Nov.–Dec. 2022**

  Synopsis Submission & Systematic literature review.

- **Feb. –May 2023**

  Learn about simulation tool and research design.

- **Sep.–Dec. 2023**

  Software implementation by Using HFSS Tool & Techniques.

- **March–July 2024**

  Hardware implementation of Antenna.

- **Aug. –Oct. 2024**

  Review of design antenna and Preparing for thesis writing.

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